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INTERFEROMETER MEASUREMENTS OF THE LONGER WAVES IN THE IRON ARC SPECTRUM.

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ABSTRACT.

The international system of secondary standards established by interferometer comparisons of the wave lengths of selected lines in the iron arc spectrum with the wave length of the primary standard, the red radiation from cadmium, extends, at present, from the ultra-violet to the red, but no extensive comparisons of these spectra existed for iron waves longer than 6750 A. Using the international iron arc as a source of secondary standards and cadmium vapor lamps similar to those used in the wave-length-meter comparisons for the primary standard, new values have been obtained for 161 lines ranging in wave length from 5534.525 A to 8824.238 A. Seventy-five of these are longer than 6750 A. The probable error of each value is of the order of 0.001 A. In the region in which these determinations overlap the international standards there is a systematic deviation indicating that the accepted international scale is nearly 1 part in 1,000,000 too large. Comparison of these values with the relative ones obtained in the same spectral interval by Burns shows good agreement if the latter are adjusted to the new scale of absolute values. A figure illustrating the dispersion of phase change at reflection in interferometer mirrors of silver and copper is given.

CONTENTS.

I. INTRODUCTION.

The international system of secondary standards of wave length, as derived from the spectrum of the iron arc, now extends from the ultra-violet (3370.789 A) to the red (6750.163 A). During the past decade, very little progress has been made in extending this system to shorter or to longer waves. The most extensive interference measurements in the region of longer waves (5434.529 to 8824.254 A) were made by Burns,[1] who determined the values of 125 iron lines relative to the international standards in the interval 5400 to 6500 A. Eversheim [2] compared the wave lengths of 17 iron lines (6003.039 to 7445.800 A) with the primary standard—the red radiation from cadmium. In the

[1] Jour. de Phys. (5), **3**, p. 457; 1913.

[2] Ann. d. Phys., **45**, p. 454; 1914.

present paper is given a table of the wave lengths of 161 lines (5434.525 to 8824.238 A) measured by interferometer comparisons with the primary standard.

II. APPARATUS AND METHODS.

In consequence of the detection of small variations in the wave lengths of certain groups of iron lines, depending upon operating conditions, the specifications for the iron arc were recently modified by the International Astronomical Union.[3]

At the same time it was recommended (loc. cit.) that the arc previously described by the International Union for Cooperation in Solar Research [4] be retained as a source for waves longer than 6000 A, since the secondary standards in this region are all stable lines and exposures with the modified arc might be rather long. Accordingly, we have used an iron arc operated on a 240-volt direct-current circuit with a current of 6 amperes, the electrodes being iron rods of 7 mm diameter separated by 6 mm, and light being taken from an axial part of about 2 mm in the middle of the arc. Since, for the longer waves, the positive flame is very weak compared with that from the negative electrode [5] the polarity was reversed during each exposure so that the positive electrode was above the negative for half the exposure and vice versa for the remaining half. This procedure gave the same photographic density to the interference fringes above and below the center of the system.

Cadmium vapor lamps of the H type similar to those used in the meter-wave-length comparisons were employed as a source of the primary standard. These lamps were made of Pyrex glass to reduce the losses due to breakage which might result from rather large changes in temperature. In actual operation, a small electric furnace held the lamp at a temperature near 300° C., and the cadmium spectrum was excited by an electrical discharge from the secondary of a transformer, whose primary was fed by 120 volts, 2 to 5 amperes alternating current.

The International Astronomical Union has adopted certain well determined values of neon wave lengths as auxiliary standards[6] which, for practical purposes, are more convenient working standards and can be accepted as equivalent to the primary standard. Some of the exposures were made simultaneously to the iron arc

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[3] Trans. I. A. U., **1**, p. 36; 1922.
[4] Trans. I. U. S. R., **4**, p. 58; 1914.
[5] Fabry and Buisson, Jour. de Phys., **9**, p. 229; 1910.
[6] Trans. I. A. U., **1**, p. 35; 1922.

and cadmium lamp, with the aid of a semitransparent mirror, which reflected light from the one and transmitted light from the other. In the remaining cases, in order to record the fainter lines, exposures of two hours were made to the iron arc and the primary standards were photographed on the same plate, before and after the exposure to iron. The mean value of the interferometer thickness as determined from the cadmium and neon exposures flanking that of iron was then used for reducing these plates. Three of the plates also received exposures to argon. A summary of all the observations is given in Table 1.

TABLE 1.—Summary of Observations on the Longer Waves in the Iron Arc Spectrum.

Plate.	Étalon.	Exposures of sources (in minutes).	Plate.	Étalon.	Exposures of sources (in minutes).
	mm			mm	
G1390....	5	Cd, 30; Fe, 120; A, 60; Ne, 12.	G1396....	10	Ne, 12; Fe, 120; Cd, 30; Ne, 12.
G1391....	7.5	Cd, 30; Fe, 120; A, 60; Ne, 15.	G1467....	10	Cd, Fe, simultaneously, 60.
G1392....	10	Cd, 30; Fe, 120; A, 30; Ne, 15.	G1468....	10	Cd, Fe, simultaneously, 60.
G1393....	15	Cd, 20; Ne, 15; Fe, 120; Ne, 15.	G1469....	7.5	Cd, Fe, simultaneously, 60.
G1395....	15	Cd, 45; Ne, 12; Fe, 120; Ne, 12.	G1470....	7.5	Cd, Fe, simultaneously, 60.

Schleussner ultra-rapid plates (40 cm by 6 cm) bathed in solutions of dicyanin were used for photographing the spectra. These plates were of extra thin glass, which permitted their bending to fit the best focus for lines and interference rings throughout the entire spectrum extending from about 5200 A to 9000 A.

The observations here described were made during 1922 when the international secondary standards (3370 to 6678 A) were being redetermined[7] in the same laboratory. Since the same methods and, to a large extent, the same apparatus were employed in both investigations it is unnecessary here to repeat what has been said there about the diffraction grating spectrograph, the interferometer, or the measurements and computations of wave lengths. The essential respects in which the present observations deviated from those on the shorter waves have been mentioned above so we can proceed at once to the presentation of the final results.

III. RESULTS.

All interferometer measurements of wave lengths greater than 5434 A in the iron arc spectrum are collected in Table 2. In the first column, the estimated relative intensities of the lines are given, and where data are available the group and class to which each line belongs according to Gale and Adams[8] is also given.

[7] B. S. Sci. Papers, No. 478.

[8] Astroph. Jl., 35, p. 10; 1912.

Column 2 contains the new wave-length values obtained by direct comparison with the primary standard, and in the two succeeding columns the number of observations and the probable error of the mean value are given for each line. "A" indicates a probable error less than 0.0007 A, "B," 0.0007 to 0.0012 A, and "C" means that the determination is poor. Columns 5 and 6 present the values and probable errors published by Burns and in the next column the values obtained by Eversheim are repeated. In the last two columns are presented, for purposes of comparison with preceding values, the present values of the international secondary standards and the interpolated values adopted by the International Astronomical Union.[9] In order to make comparisons with a considerable number of the accepted secondary standards we begin our table with 5434 A, thus including 25 standards, 4 of which belong to group d.

TABLE 2.—Wave Lengths in the Iron Arc Spectrum.

Intensity, group, and class.	λB. S.	Number of observations.	Probable error.	Burns.	Probable error.	Eversheim.	Secondary standards.	Interpolated.
4 a 4	5434.525	6	B	529	−2	......	527	528
5 a 4	46.919	6	A	922	A	......	......	921
6 a 4	55.614	8	B	......	......	......	614	615
3 d 5	76.577	4	A	......	......	......	......	......
4 a 3	5497.520	10	A	520	+2	......	522	522
4 a 3	5501.469	10	A	......	......	......	......	470
5 a 3	06.782	10	A	......	......	......	784	784
2 a 4	35.420	2	C	......	......	......	......	......
2	65.700	2	C	......	......	......	......	......
6 d 5	69.631	10	A	......	......	......	633	......
7 d 5	72.856	10	B	......	......	......	......	......
4 d 5	76.102	8	A	......	......	......	......	......
10 d 5	5586.770	10	B	......	......	......	772	......
5 d 5	5602.959	10	B	962	C	......	......	......
10 d 5	15.658	10	B	......	......	......	661	......
5 d 5	24.555	10	B	......	......	......	......	......
2 d 5	38.270	3	C	276	B	......	......	......
5 d 5	58.834	8	B	......	......	......	836	......
3	5662.529	7	B	......	......	......	......	......
3	5701.552	8	B	553	A	......	......	......
4	09.392	10	A	395	B	......	396	......
2	17.845	4	C	852	B	......	......	......
2	31.770	3	C	773	B	......	......	......
3	53.138	7	B	142	A	......	......	......
5	63.009	9	A	......	......	......	013	......
2	5775.096	4	A	101	B	......	......	......
2	5934.675	4	B	682	D	......	......	......
2	5956.693	3	C	695	D	......	......	......
3	6003.033	7	A	036	B	039	......	......
4	08.577	6	B	584	B	......	......	......
5	24.060	9	B	......	......	......	......	......
2 b 4	27.056	5	C	......	......	......	059	059
2	42.088	5	C	092	B	......	......	......
7 b 4	65.489	9	A	......	......	491	492	492
3	78.484	3	C	485	B	......	......	......

[9] Trans. I. A. U., **1**, p. 41; 1922.

TABLE 2.—Wave Lengths in the Iron Arc Spectrum—Continued.

Intensity, group, and class.	λB. S.	Number of observations.	Probable error.	Burns.	Probable error.	Eversheim.	Secondary standards.	Interpolated.
1	6089.566	4	C	570	C			
2	6127.910	6	B	919	B			915
5 b 4	36.621	10	B					624
5 b 4	37.699	10	B			703	701	702
2	51.624	4	A					
2 b 4	57.731	6	A	736	A			734
2	65.364	4	C	372	B			368
3 b 4	73.342	6	A	347	C			344
7 b 4	6191.565	10	A				568	568
3 b 4	6200.320	8	A	323	A			323
4 b 4	13.435	10	A	439	A			
4 b 4	19.286	10	A	289	A			290
7 b 4	30.730	10	A				734	734
2	32.661	3	C					
5 d 5	46.334	10	A	339	C			
5 b 4	52.564	10	B	567	B			567
3 b 4	54.262	7	B	268	B			267
3 b 4	56.366	7	B	372	B			
4 b 4	65.140	9	A	143	+2	145	145	145
2	80.621	6	A	625	B			
3 b 4	6297.800	10	B	801	A			803
5 d 5	6301.515	5	B					
4 b 4	18.025	10	A			030	028	028
2	22.693	6	A	697	A			696
5 b 4	35.338	10	A	343	−2		341	342
4 d 5	36.841	10	A	842	B			
2	44.155	6	B	158	C			
3	55.037	6	B	040	B			
3	80.748	6	A	752	C			753
7 b 4	6393.608	10	A				612	612
8 d 5	6400.018	10	B					
4	08.034	10	A	042	C			
6 d 5	11.666	10	A					
5 b 4	21.356	10	A					362
6 b 4	30.853	10	A	857	+2	856	859	859
3	62.732	9	A	737	A			738
2	75.632	6	A					639
2	81.878	8	A	882	B			
8 b 4	6494.988	10	B	991	+2	991	993	993
3	6518.375	6	A	378	B			382
7 b 4	46.247	10	A	247	A	250	252	252
3	75.024	6	A	032	B			029
5 b 4	92.922	10	A	925	B	920	928	927
4 b 4	6593.876	8	B					
3	6609.117	6	B	123	A			125
2	27.558	4	B					
4	63.447	9	A	454	A	449		455
7 b 4	6677.994	10	A	8.000	A	7.997	8.004	8.001
2	6703.573	4	A					
2	33.164	4	C					
4	50.157	10	A	164	A	163	163	165
2	6752.724	4	B					
2	6806.851	6	A					
3	28.612	5	A	617	C			
3	41.355	8	A					
3	43.676	8	A	681	C			
5	55.179	9	B	184	C			
2	6885.772	6	C					
3	6916.709	6	B	712	D			
2	33.628	4	C					
5	45.211	10	A	215	B	216		
2	51.271	3	B					
5	78.857	10	A	861	A	862		
2	88.531	6	A					
4	6999.912	5	A	932	D			

TABLE 2.—Wave Lengths in the Iron Arc Spectrum—Continued.

Intensity, group, and class.	λB. S.	Number of observations.	Probable error.	Burns.	Probable error.	Eversheim.	Secondary standards.	Interpolated.
3	7022.976	7	B					
3	38.255	7	B	257	C			
4	68.418	10	B	421	A			
4	7090.410	10	A	416	B			
2	7107.464	4	A					
2	12.178	4	B					
5	30.946	10	B	958	C			
2	32.996	6	A					
6	64.472	10	B	481	B			
3	81.222	6	C					
8	7187.341	10	B	348	B	356		
7	7207.422	6	C	431	A	442		
2	19.690	6	A					
3	23.670	6	A	677	C			
3	39.896	6	A	914	D			
2	84.843	4	C					
3	88.764	6	A					
5	7293.073	9	B	091	C			
3	7307.938	5	A					
4	11.103	5	A					
3	20.694	4	C					
4	86.394	3	C					
6	7389.423	10	B	437	B			
2	7401.691	5	B					
7	11.184	10	A	192	C			
3	18.676	6	A					
1	43.031	4	B					
8	45.778	10	B	781	A	800		
3	91.678	6	B					
8	7495.092	10	B	106	B			
2	7507.300	5	C					
8	11.047	10	A	054	C			
4	31.178	10	C	192	C			
2	46.177	4	A					
4	68.931	6	A	929	D			
4	83.801	9	B					
6	7586.050	10	B					
3	7620.538	6	B					
2	53.783	5	C					
3	61.230	5	B					
4	7664.306	10	A	304	C			
3	7710.397	5	B					
4	48.282	10	A	285	C			
5	7780.594	8	B	597	C			
5	7832.233	10	B	243	C			
6	7937.172	10	B	182	C			
5	45.882	10	C	889	C			
4	7998.980	10	C	986	B			
1	8028.356	4	B					
4	46.084	7	B	087	B			
4	8085.207	4	B	219	B			
1	8198.960	4	C					
5	8220.413	10	B	422	B			
5	8327.069	10	A	080	B			
2	31.956	4	C					
4	8387.787	10	B	785	B			
2	8468.422	5	A	427	D			
1	8514.088	5	B					
2	8661.915	5	C	920	D			
3	8688.641	6	B	640	C			
2	8824.238	5	A	254				

Wave-length comparisons by means of interferometers, whose plates are covered by thin metallic films, always involve a consideration of the phenomenon known as dispersion of phase change. At reflection from metallic films light apparently penetrates the films a short distance and the amount of this penetration is some function of the wave length. When wave lengths in different spectral regions are compared it is, therefore, necessary to correct for the variation in penetration or change of phase. Methods of measuring this variation have been described by Fabry and

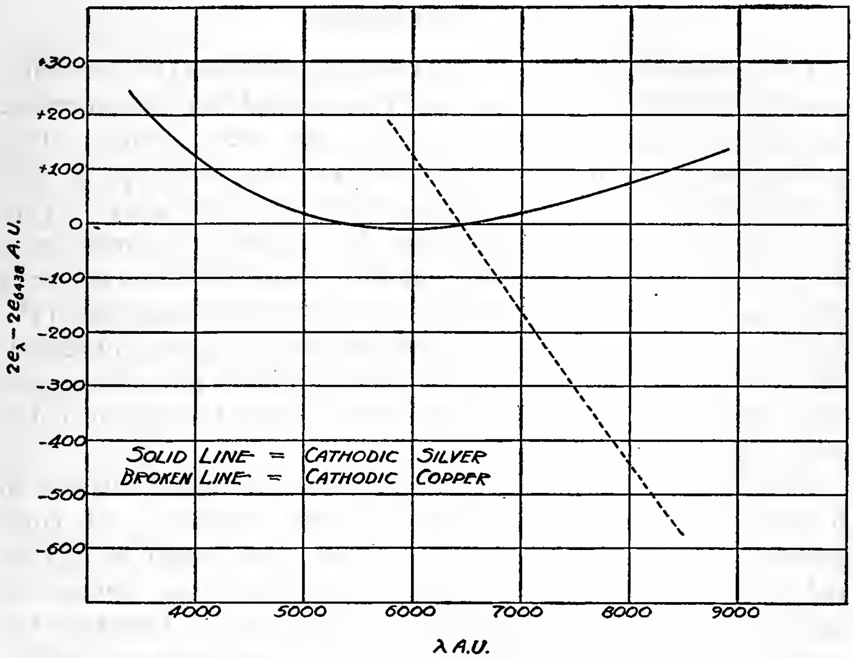

FIG. 1.—*Dispersion of phase change at reflection from silver and copper films.*

Buisson,[10] who also gave examples of phase-change dispersion for metallic films of silver and nickel in the red to ultra-violet spectral interval. Extensive wave-length measurements at this bureau have involved similar investigations and the results, especially for the behaviors of different films in the infra-red, may be of interest. The method of large and small étalons [11] has always served us in determining the phase-change dispersion. Figure 1 illustrates the variation of the "optical surface" in interferometer films of silver and copper, the deviation of the optical surface for any particular wave length from that for the cadmium line (6438.4696 A) being

[10] Jour. de Phys. (4), 7, p. 417; 1908.

[11] Meggers, B. S. Bull., 12, p. 199; 1915.

plotted as ordinates and wave lengths as abscissas. The silver films were used in the redetermination of the secondary standards (see preceding paper) as well as for the longer waves reported in the present paper, and have thus been investigated throughout a wide range of spectrum (3300 to 8800 A). The data for the copper films were obtained several years ago in wave-length measurements in the spectrum of argon.[12] They are given here because they also extended into the infra-red and show a phase-change dispersion which is strikingly different from that of silver.

IV. DISCUSSION.

In the redetermination of the secondary standards (see preceding paper) from the 12 mm iron arc it was noted that a systematic deviation, averaging 0.0049 A, from the international values existed for the 14 lines of group b between 6027 and 6678 A; that is, the accepted international scale appeared to be nearly 1 part in 1,000,000 too large in this interval. A similar discrepancy is revealed by the above results (column 2) from the 6 mm iron arc, the same 14 lines averaging 0.0044 A smaller wave length than the accepted international values. The difference of 0.0005 A between the two new series of observations may represent a real change in wave length of the so-called stable lines when the length of the arc is changed.

Since the values given by Burns were determined relative to international secondary standards, in order to make a fair comparison of his relative values with ours, the former should be reduced by about 0.005 A at 6438 A, and for other regions by amounts proportional to the wave-length ratios. Omitting the values which are poorly determined, such a comparison on 79 lines shows that the average difference is only ± 0.002 A, and also that there is no appreciable systematic difference between our values and the adjusted Burns values. The agreement between our values and those of Eversheim is quite unsatisfactory, but no explanation of the deviation is offered.

WASHINGTON, August 20, 1923.

[12] Meggers, B. S. Sci. Papers, **17**, p. 193; 1921.